

Progress Report No. 13

"A Theoretical and Experimental Study of the Ionosphere  
Using Radio Signals from Earth Satellites"

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## Introduction

This report describes the continuation of ionospheric research, using radio signals from artificial earth satellites, being conducted at the University of Illinois under NASA sponsorship since 1959. The research program is mainly an experimental one; however, several theoretical problems arise, from time to time, which are pertinent to the interpretation of the experimental results, and hence a theoretical research program is necessary for a thorough understanding of the phenomena. The subjects of experimental research can be divided into two parts. These are (1) the investigation of small-scale ionospheric irregularities by means of scintillation of radio beacon signals, and (2) the investigation of the columnar electron content of the ionosphere and the exosphere by observation of the Faraday rotation of the planes of polarization of the satellite radio beacon signals and Doppler shifts of the frequencies of these signals. The theoretical research can be divided into three parts. These are (1) wave propagation, (2) physics of formation of ionospheric irregularities and (3) aeronomy of the ionosphere and the magnetosphere.

## Field Station Operations and Equipment

Five field stations have been in operation during the period of this report. These are Urbana, Illinois; Houghton, Michigan; Adak, Alaska; Baker Lake, Northwest Territories; and Bozeman, Montana. Operation of the Adak station has been transferred from the U.S. Army Signal Corps to the Office of the Chief of Naval Operations. The Bozeman station, which is situated at approximately the same geomagnetic latitude as the Urbana station and at about the same geographic latitude as the Houghton station, has been recently set up as a

cooperative venture with Montana State University, and its activities are being supervised by Professor Robert Leo.

Radio beacon signals from HE-B are being recorded at all five stations while radio beacon signals from HE-C are being recorded at Urbana only. HE-C signals are being recorded for three passes every day instead of for only one pass in view of the usefulness of the results of the analysis of those data. It is proposed to record HE-C signals at Houghton and Bozeman also in the near future. Recording of radio beacon signals from OGO-A has been discontinued during the report period due to severe limitations imposed upon the recording and analysis of the data by the spin of the satellite. This discontinuation was also motivated in anticipation of obtaining better data from OGO-B which was launched in June, 1966.

Equipment development during this period has been concentrated on two main efforts. The first effort was directed at getting the receivers, antennas, and Sanborn recorder in top operational condition for the long observation periods of OGO-B. The Sanborn was reconditioned with assorted new parts for the drive assembly. The Smythe receiver (phase locked receiver 40/360 MHz and sidebands) was completely re-aligned and checked. The 360 mc preamplifier (4 db noise figure) was replaced with another preamplifier with a 1.5 db noise figure. The antenna arrays used on OGO-A (circular polarization) were converted for use with OGO-B (plane polarization).

The second effort was the design of the necessary equipment for the reception of data from synchronous satellite or lunar reflected signals. Solid state preamplifier converters were designed to operate with the Model B receiver at 136 mc and 220 mc. The receivers have a noise figure of 4 db or less and a minimal usable sensitivity of -145 dbm.

### Experimental Program

Results of analysis of 1961 Omicron Faraday data at 54 Mc/s have been accepted for publication in the Journal of Geophysical Research. In this work, the electron content and slab thickness results for the period extending from July 1961 to October 1964 have been studied for the diurnal, seasonal and sunspot cycle dependence and have been related to the physical processes such as the diffusion coefficient and the electron and ion temperatures by using a diffusion transport layer model. The seasonal dependence of electron content and slab thickness were found to be in disagreement. Possible causes of the seasonal anomaly were examined in terms of a diffusion transport layer. The most favored mechanism seemed to be the change of composition of the minor constituent  $O_2$  or  $N_2$ . Analysis of Faraday rotation data from 1961 Omicron recorded at Houghton has been completed and the results of electron content are being interpreted and compared with the results for Urbana.

Analysis of Faraday rotation data from EE-B (S-66) recorded at Urbana has progressed well, during the period of this report, using observations on the two closely spaced frequencies 40 Mc/s and 41 Mc/s. The method employs nonlinear interpolation between the null times in order to compute the differential Faraday rotation between the 40 Mc/s and 41 Mc/s signals. A similar analysis of EE-B data recorded at Houghton has just begun. Data recorded at Bozeman are being analyzed at Montana State University. In addition to studying the diurnal, seasonal, magnetical and solar cycle dependence of the electron content results for the three stations separately, the results will be combined for the purpose of investigating the pronounced electron density troughs deduced from observations using the topside sounder aboard the Canadian satellite Alouette and confirmed by data obtained from the flight of a planar ion trap

on the polar-orbiting, earth-oriented satellite, 1963-42A. Also, the latitudinal gradients of electron content along the meridian of Urbana and Houghton will be examined.

Reduction of HE-C Faraday rotation data for the period May 1965 through October 1965 into electron content values has been completed. An elaborate computer program for obtaining electron content from these data has been written. The method of analysis employs the Faraday fading data at 40 Mc/s obtained by using an electrically rotating goniometer in addition to the conventional Faraday rotation records of 40 Mc/s and 41 Mc/s signals received on fixed dipoles. This combined use is necessitated by the almost west to east orientation of the sub-ionospheric path of the satellite as viewed from Urbana. Results obtained thus far indicate diurnal behavior of electron content consistent with previous findings and contain valuable information concerning the longitudinal gradients, especially during sunrise and sunset periods. These are being examined and related to ionospheric physical processes. The computer program has recently been extended to determine the irregular variations of the electron content. The method consists of fitting a second or third degree polynomial which gives the best fit in the least-squares sense to the computed electron content curve. The fitted curve represents the smoothed background ionization whereas the deviation of the actual curve from the fitted curve represents the irregular variation of electron content. The plots of electron content from individual passes are being analyzed using this method for a study of large scale irregularities.

Lack of group delay data to establish a reference value for the Doppler content and the inability to determine, to a sufficient degree of accuracy, the spin rate of the satellite because of the poor quality of the 360 Mc/s signal amplitude fading record have imposed severe limitations upon the analysis

of OGO-A data. The meager amount of satisfactory Faraday data have been partially analyzed pending receipt of a computer program, from NASA, which takes into account the lunar perturbations in computing the highly elliptical orbit of the satellite.

A lunar tidal analysis of the Faraday rotation data from synchronous satellites was initiated during the period of this report. Data recorded at Hawaii from Syncom III satellite during January 1965 was kindly supplied by the Stanford University group for this purpose. Only one month's data are being analyzed as a preliminary measure and initial results indicate significant lunar effect.

Tabulation of scintillation indices on 40 Mc/s from EE-B and recorded at Adak for the period October 1964 to October 1965 has been completed. The conjugate correlation of these indices with those for Wellington, New Zealand, supplied by Dr. J. Mawdsley of Victoria University, is in progress.

During the period of this report, considerable work was done to improve and modify existing computer programs and to write new programs. Among the new programs, those for EE-B and EE-C data analysis have been perfected. Steps have been taken to initiate a computer analysis of Doppler data. This program is currently in the check-out stage.

#### Theoretical Program

The problem of wave propagation through ionospheric irregularities was continued. The results of the work on cross-correlation functions of spherical waves propagating through a slab containing anisotropic irregularities has been published in the Journal of Atmospheric and Terrestrial Physics. In this and previous work, the average refractive index of the ionosphere was considered

as unity, corresponding to a homogeneous "background." But in reality, the ionosphere is both inhomogeneous and anisotropic; the problem is then more complex. As a first step, the effects of inhomogeneity and anisotropy are being considered separately. The general problem of spherical waves propagating through an inhomogeneous medium containing irregularities has been investigated. Mean square values and correlation functions of the field quantities have been calculated, including the effects of the inhomogeneous "background" to the first order. The results are being put together as a technical report.

The study of formation of ionospheric irregularities was continued. A plasma dynamic model has been proposed to explain certain irregularity phenomena. It has been found previously that the instability caused by the combining effort of gravitational field and positive electron density versus height gradient may be a possible cause of the formation of irregularities in certain ionospheric regions. This study has been extended by taking into account the effect of neutral particle coupling. It is found that the criteria for instability are modified, but the main features still remain. The results of this study were presented at the 1966 Spring meeting of URSI and have been accepted for publication in Radio Science.

The F2 region aeronomy study has been continued. Work has progressed on numerical solutions of parabolic partial differential equations and in particular the electron density continuity equation. Computer program for this work is nearing completion.

#### Papers Presented at Conferences

The following paper was presented at the 1966 Spring URSI meeting in Washington, D. C.

C. H. Liu and K. C. Yeh, "Gradient Instabilities as Possible Causes of Irregularities in the Ionosphere."

## Publications

The following papers have been published or have been accepted for publication during the period of this report.

1. C. H. Liu, "Cross-Correlation Function of Spherical Waves Propagating Through a Slab Containing Anisotropic Irregularities," J. Atmos. Terr. Phys., Vol. 28, May 1966, pp. 385-395.
2. C. H. Liu and K. C. Yeh, "Low Frequency Waves and Gradient Instabilities in the Ionosphere," to be published in the July 1966 issue of Physics of Fluids.
3. C. H. Liu and K. C. Yeh, "Gradient Instabilities as Possible Causes of Irregularities in the Ionosphere," to be published in the November 1966 issue of Radio Science.
4. K. C. Yeh and B. J. Flaherty, "Ionospheric Electron Content at Temperate Latitudes during the Declining Phase of the Sunspot Cycle," accepted for publication in J. Geophys. Res.

## Personnel

The following persons have contributed to the work of the project during the report period.

\*Dr. G. W. Swenson, Jr., Professor of Electrical Engineering and Research Professor of Astronomy

\*Dr. K. C. Yeh, Associate Professor of Electrical Engineering (Dr. Yeh has been on sabbatical leave during most of the report period)

Dr. N. Narayana Rao, Assistant Professor of Electrical Engineering

Dr. C. H. Liu, Research Associate in Electrical Engineering

Mr. B. J. Flaherty, Research Engineer

Mr. T. R. Pound, Research Assistant

Mr. A. P. Weise, Research Assistant

Mr. D. Simonich, Research Assistant

\*Mr. K. C. So, Research Assistant

Mr. Anthony Szelpal, Electronics Technician II

Several hourly student assistants have also been employed.

\*not paid from the grant during this report period.